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A LINGUISTIC MODEL DEVELOPMENT FOR DESCRIBING SPELLING-TO-SOUND CORRESPONDENCES WAS UNDERTAKEN AND A NUMBER OF SPELLING-TO-SOUND PATTERNS ANALYZED, CONTINUING AN EARLIER STUDY PERFORMED UNDER PROJECT NO. S-039 (ED 003 445). RESEARCH EMPHASIZED VOWEL SPELLINGS AND THE INFLUENCE OF VARIOUS CONSONANTS UPON THE PRONUNCIATIONS OF THESE SPELLINGS. IT WAS BASED ON THESE HYPOTHESES--(1) THAT ENGLISH SPELLING RELATES NOT ONLY TO PHONOLOGY, BUT ALSO TO MORPHOLOGY AND SYNTAX AND (2) THAT, WHEN VIEWED WITH THIS UNDERSTANDING, A MUCH HIGHER DEGREE OF REGULARITY EMERGES THAN WHEN UNDERSTANDING IS CONFINED TO A SIMPLE LETTER-TO-SOUND RELATIONSHIP. RAW DATA WERE ACCUMULATED THROUGH USE OF A DIGITAL COMPUTER. SUCH BASIC SETS OF CORRESPONDENCES AS--(1) SPELLING-TO-MORPHOPHONEME, (2) MORPHOPHONEME-TO-MORPHOPHONEME, AND (3) MORPHOPHONEME-TO-PHONEME WERE ESTABLISHED. IT WAS CONCLUDED THAT THE MAJOR EMPHASIS IN TEACHING THE RELATIONSHIP BETWEEN SPELLING AND SOUND SHOULD CENTER ON SPELLING-TO-MORPHOPHONEME PATTERNS. ADDITIONAL STUDY WAS RECOMMENDED, HOWEVER, BEFORE ADAPTING THE MATERIAL PRESENTED TO THE TEACHING OF READING. (JM)

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RULES TO AID IN THE TEACHING OF READING

Research Project No. 2584

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PREFACE

This Final Report for U.S. Office of Education Contract OE-4-1--206 covers research on English spelling-to-sound correspondences done at Stanford University from June 1, 1964 until February 28, 1965. While the material presented here is entirely new, the basis for this study is the same as that for U.S. Office of Education Contract S-039, and much of the preliminary work was done by the same authors under that contract. A familiarity with the Final Report for Contract S-039 (Weir, 1964) will be helpful in reading the present Report.

The raw data upon which this study is based consists of a tabulation of the spelling-to-sound correspondences in approximately 20,000 English words. The criteria for selection of these words, the transcriptions of their pronunciations, and a number of other pertinent facts are contained in the Final Report mentioned above.

From these tabulations, various correspondence patterns were derived and a basic model for mapping from the spelling level to a morphophonemic level and then to a phonemic level was constructed. In the previous Report, this model and correspondence patterns for consonants and for some vowel spellings were described. In this Report, various modifications have been made to the model and consequently to the correspondence patterns. In addition most of the remainder of the vowel correspondences are described along with some morphophonemic patterns. While the material presented here should provide an adequate basis for developing sound reading materials, considerable research still remains to be done in the area of spelling-to-sound correspondences. Suggestions for such work are included in Section 7.

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1. PROBLEM ON WHICH RESEARCH WAS FOCUSED.

The relationship of spelling-to-sound in English has long been a matter of confusion and conjecture. Traditional, if phonetically oriented, views have centered on direct grapheme-to-phoneme correspondences (Hall, 1962) and upon the grapheme-phoneme parallel (Pulgram, 1951). That morphemics and morphophonemics are important for understanding the writing system has been suggested previously (Bradley, 1914; Vachek, 1962), but prior to the work of the present authors no attempt was made to develop this notion in a systematic fashion.

In the previous Report (Weir, 1964) we advanced the hypothesis that if the writing system were viewed as a morphophonemic system, a much higher degree of regularity could be shown than if a simple letter-to-sound relationship were assumed. Considerable evidence for that view was presented in the Report. The present work is a continuation of this investigation, concentrating upon the analysis of various correspondence patterns.

While other topics will be discussed in this Report, the major emphasis of our current research and of this Report lies in the following areas:

1. The graphic basis of spelling-to-sound correspondences.
2. The patterning of vowel spellings.
3. The influence of {w}, {l}, and {r} upon vowel correspondences.
4. Basic morphophonemic patterns.

An attempt has been made in these analyses to present not only the major and minor patterns which underlie the various correspondences, but also to present exhaustive lists of exceptions. As was emphasized in the previous Report, we consider it essential to the teaching of reading to classify irregularities according to the levels on which they occur. To do this requires a complete, structural description of all spelling-to-sound correspondences. It should be no surprise, therefore, to any linguist to find that what seemed to be an irregularity last year, has this year become part of a regular pattern. The quest for patterning in a system as complex as the spelling-to-sound one is a never-ending search.

2. OBJECTIVES AND HYPOTHESES

The chief objectives of the present research are, first, to develop a sound linguistic description of spelling-to-sound correspondences in English words, and then to suggest, on the basis of such a description, how the linguistic evidence could best be applied to the teaching of reading. Under U.S. Office of Education Contract S-039, a model for describing spelling-to-sound correspondences was developed and a considerable number of spelling-to-sound patterns were analyzed. Under this project, research on both the model and on spelling-to-sound patterns was continued with special emphasis upon vowel spellings and the influence of various consonants upon the pronunciations of these spellings. While some minor modifications have been made in the model and in some of the patterns previously described, the results of our research during this period have strengthened our original notion that English spelling should be viewed as a morphophonemic system.

The statement repeated below is taken from our previous Report. It remains as a concise summary of the hypotheses upon which this work is based.

> "The hypotheses on which this research is based are that English spelling relates not only to phonology, but also to morphology and syntax, and that when viewed with this understanding, a much higher degree of regularity emerges than does emerge when we confine ourselves to a simple letter-to-sound relationship."

3. RELATED RESEARCH

Most of the American research related to our efforts is described in the project reports of Project Literacy (see Levin, 1963, 1964). While none of these reports bear directly upon the work reported here, numerous suggestions relevant to our research have been derived from them.

Studies of English spelling-to-sound relationships can be found from the 16th century on. A summary of the less well known early works can be found in Abercrombie (1948), while analyses of the better known early works are contained in Dobson (1959). More recent studies in this area have been conducted by Hall (1961, 1962) and Soffietti (1955). What is most remarkable about all these works is the great similarity between the earlier and later works. Except for minor differences in pronunciation, the work of Douglas in 1740 remains today as the most complete analysis of direct spelling-to-sound correspondences (Halmberg, 1956). The differences between Douglas and Hall (1961) or Soffietti (1955) are chiefly in terminology and thoroughness.

Some basic notions on the relation between writing and speech can be found in Bradley (1914), Bolinger (1946), Uldall (1944), Pulgram (1951), Vachek (1962), and Stetson (1937). The two latter deal with the so-called grapheme-phoneme parallel (cf. section 4.3 below). Francis (1958, pp. 430-79) has the most complete discussion of graphemics.

By far the most extensive treatment of English graphotactics is to be found scattered throughout volume one of Jespersen's monumental Modern English Grammar on Historical Principles (Jespersen, 1961). Barrett (1963) has done an extensive study of what we call graphemic allomorphs, although she restricted her work to nominal complexes. Word stress has been investigated extensively by Kingdon (1958) and Waldo (1964).

4. PROCEDURE

4.1 Collection of Data

A digital computer was used to accumulate most of the raw data used for this study. Descriptions of the routines developed for this work are included in Appendix A. (Some of these routines were begun under the previous study and completed under the present study). In addition, use was made of the Normal and Reverse English Word List developed at the University of Pennsylvania (Brown, 1963) and of various dictionaries (Merriam Webster III, 1963; Kenyon and Knott, 1951; Oxford English Dictionary, 1933). For more detailed information, see Weir (1964).

In addition to the computer work mentioned above, data processing experiments were started on the application of some of the results obtained in this study to the automatic processing of a large rhyme collection. One goal of this work was to see if any of our results could facilitate the editing and classification of a large number of English rhymes. Another goal was to see if the classification of graphemic units based upon English rhymes would agree with the classification obtained through direct studies of spelling-to-sound correspondences. While the results obtained from this particular study are encouraging, further research is needed in this area before any hypotheses can be advanced. Although these results have been useful in our studies of graphemics, they are not discussed directly in this report. More details will be forthcoming in the near future.

4.2 Symbology

Three basic sets of correspondences have been established: spelling-to-morphophoneme, morphophoneme-to-morphophoneme, and morphophoneme-to-phoneme. Every correspondence involves an initial item, an environment in which the item must appear for the correspondence to hold, and a corresponding item. The initial items are one or more spelling units (see Section 4.3) or morphophonemes; the corresponding items are one or more morphophonemes or phonemes. Spelling units are enclosed in brackets ⟨⟩, morphophonemes are enclosed in braces { } and phonemes are enclosed in slant lines / /. The description of the environment is enclosed in parentheses and immediately follows the initial item. Examples

Rule: ⟨b⟩ (debt, doubt, subtle) → {ø}

Interpretation: The letter ⟨b⟩ in the words debt, doubt, and subtle is mapped into a zero morphophoneme.

Rule: ⟨c⟩ (--i/y/e) → {s}

Interpretation: The letter ⟨c⟩ followed by ⟨i⟩, ⟨y⟩, or ⟨e⟩ is mapped into the morphophoneme {s}.

Rule: {ŋg} (--/) → {ŋ}

Interpretation: The morphophoneme cluster {ŋg} becomes {ŋ} if followed by word juncture

Rule: {š} (ALL) → /š/

Interpretation: All occurrences of the morphophoneme {š} are mapped into the phoneme /š/.

Spelling units are represented by the graphemes ⟨a⟩ through ⟨z⟩ (contractions and hyphenated forms are not included in this study). For a discussion of spelling units, see Section 4.3. Morphophonemes, because of restrictions of the typewriter are represented by lower case phonemic symbols, just as are phonemes. A description of the phonemic system used for this study is given in Section 4.4.

The environment description consists of either a list of words or the designation of a spelling position. If the word list includes more than three words, the symbol L appears in the parentheses, an indication that the correspondence holds for the words in a list following the rule. If the word list consists of less than four words, these words will appear in the environment parentheses. Potential ambiguity among several appearance of the same grapheme in a word is resolved by underlining the particular grapheme concerned. Thus, ⟨a⟩ (dr$\underline{a}$ma, f$\underline{a}$ther, m$\underline{a}$mma) → [a] .

A spelling position is sometimes defined first by a qualifier, I,M,F, indicating either initial, medial, or final position in a word, and then by specific environmental features, described with the following symbols:

Symbol	Definition
ELSE	in all other cases
--X	before X
X--	after X
X--Y	between X and Y
C	consonant
V	vowel
/	or
⌿	juncture
ALL	in all cases
(x)	optional feature x

Stress is indicated in the following ways for an arbitrary letter or morphophoneme x:

$\acute{x}$ primary stress

$\grave{x}$ secondary stress

$\bar{x}$ either primary or secondary stress

$\underline{x}$ unstressed

x stress is irrelevant for our purposes

A short dash before an environmental element indicates non-initial position for that element: a short dash following indicates non-final position, (The long dash indicates where the spelling unit or morphophoneme occurs.) Thus, the rule

⟨x⟩ (-y--) → [z]

reads "the grapheme ⟨x⟩ after non-initial ⟨y⟩ is mapped into [z] ."

The rule ⟨xy⟩ → ⟨x⟩ + ⟨y⟩ reads "For the mapping of ⟨xy⟩, apply the separate rules for ⟨x⟩ and ⟨y⟩".

Examples of Environment Descriptions

Rule: ⟨x⟩ (I) →
Int: Initial ⟨x⟩

Rule: ⟨x⟩ (M) (V --V)
Int: Intervocalic ⟨x⟩

Rule: ⟨x⟩ (--C)
Int: Preconsonantal ⟨x⟩ in either initial or medial position

Rule: {x̄} →
Int: Stressed {x}

Rule: {x̲} (--⁄)
Int: Unstressed {x} in pre-junctural position

Rule: {x} (a/b/c --)*
Int: {x} preceded by {a}, {b}, or {c}

Rule: {x} (--V̲)
Int: {x} followed by an unstressed vowel

Correspondence rules are ordered. To find the phonemic representation of a graphemic form, the following steps should be taken:

(1) Apply all applicable spelling-to-morphophoneme rules, beginning with the largest string of graphemic units (moving left to right) to which a rule can be applied.

(2) Repeat (1) with the morphophoneme-to-morphophoneme rules, operating on the morphophonemes obtained from (1).

(3) Repeat (1) with the morphophoneme-to-phoneme rules, operating on the morphophonemes obtained from (2).

In addition, within all of these steps the given rules must be applied in the prescribed order. This hierarchical arrangement is crucial.

4.3 Selection of Spelling Units

The selection of spelling units is determined by the spelling-to-morphophoneme rules. For the most part, these choices are dictated by the morphophonemic forms which are derived from the spelling units in question. Thus, ⟨ch⟩ is treated as a single unit because the morphophonemes [č], [k], and [š] which are derived from it, are single units. For the same reason, ⟨ai⟩, ⟨oi⟩, and ⟨ow⟩ are treated as single units as are ⟨gh⟩, ⟨ph⟩, ⟨sh⟩, and ⟨th⟩ and various other clusters. All of these unit clusters thus far agree with the traditional divisions made by orthographers. Where the system presented here deviates from tradition is in the treatment of such grapheme clusters as ⟨qu⟩, ⟨ng⟩, and ⟨rh⟩.

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* In this Report the standard typewriter a̲ will be used for the phonetic symbol /ɑ/.

While ⟨q⟩ occurs almost invariable in the combination ⟨qu⟩, there is no reason to treat this cluster as a unit. If we did so, then we should for the same reason treat final ⟨-ve⟩ as a cluster since ⟨v⟩ does not occur in word final position except in rare borrowings. And there is no reason to stop here. ⟨gu⟩ could also be taken as a cluster in *guest* and *guess* since the ⟨u⟩ functions as a buffer between ⟨g⟩ and ⟨e⟩.

Most of these clusters demonstrate facts about English graphotactics only and our purist instincts require that such facts be placed in their proper place. To include ⟨qu⟩ as a single unit would be inconsistent with the general form of the spelling-to-sound model which has been adopted here. ⟨q⟩ is mapped invariable into [k] and ⟨u⟩, when preceded by ⟨q⟩ is mapped into [w], with some exceptions. Graphotactical rules are treated independently of the mapping rules since the majority of them account for the various spellings of the same morpheme and have no place in the mapping rules. To write a single rule for ⟨qu⟩ would, therefore, be inconsistent with the model and uneconomical. This argument also applies to ⟨-ve⟩, and ⟨gu⟩ where the ⟨e⟩ and the ⟨u⟩ are properly parts of the environments of ⟨v⟩ and ⟨g⟩ and not components of unit forms.

⟨ng⟩ has been treated traditionally as a unit cluster, in word-final position, representing the sound [ŋ].

> "The digraph ng, as in *sing*, *singing*, represents the voiced tongue-back velar nasal continuant corresponding to the voiced tongue-back stop *g*, and the voiceless tongue-back stop *k*."
>
> Webster's New Collegiate Dictionary
> pg. XIV.

Consider the adjective *long*. Under the traditional view we have for the positive form the mapping

l → l
o → ɔ
ng → ŋ

But the comparative and superlative forms require that ⟨ng⟩ be split to account for both [ŋ] and [g]: [lɔggər/, /lɪŋgɪst/. In the parallel cluster ⟨mb⟩ as in bomb, however, the traditional view considers ⟨b⟩ as a silent grapheme which comes to life in bombard because of the syllable division.

"b is usually silent after m in the same syllable, as in bomb, climb, thumb, etc."

Webster's New Collegiate Dictionary
pg. XI

While the syllable division criterion is meaningless on the graphemic level in forms like bombing, the silent grapheme approach, nevertheless, is sound and should be extended to ⟨ng⟩.

By treating ⟨ng⟩ as two units we gain not only consistency but generality. The rule that transforms {n} before the velar stops {g} and {k} to {ŋ} that must be written for words like ankle and congress can now be applied to long as well as sing and to the other forms which end in ⟨ng⟩. The initial morphophonemic forms become {lɔŋg},{sɪŋg}, etc., and a single rule for dropping the final {g} except before the regular comparative and superlative endings accounts for the final phonetic forms.

The graphemic sequence ⟨gn⟩ can be either a functional unit corresponding to {nj} (list A below) or a sequence of two units (lists, B, C and D) which correspond to {g} + {n}.

A	B	C	D
cognac	cognate	gnarl	align
lorgnette	ignite	gnash	benign
mignonette	ignore	gnat	design
vignette	magnet	gnaw	impugn
	pugnacious	gnosis	malign
	stagnant	gnostic	sign

In list A ⟨gn⟩ is a single functional unit, corresponding to {nj}. A preceding simple vowel (see Section 5.) should, in this case, be mapped into its complex morphophonemic alternates (see Section 5.1) which is the case for cognac. Vignette has an unstressed first syllable, which may explain its deviation from this pattern, but mignonette has secondary stress on the first syllable, and must therefore be classed as an exception.

In lists B, C and D ⟨gn⟩ is a sequence of two functional units which are mapped into {g} + {n}. Each {gn} cluster in List B is in intervocalic position within a single morpheme and is consequently mapped onto the phonemic level as /gn/. Since ⟨gn⟩ is a cluster of two units in this list, the simple vowel spellings before ⟨gn⟩ are mapped into their simple morphophonemic alternates, and then, eventually, onto the phonemic level (in the examples shown) as simple alternates. Thus, /kágnet/, /ɪgnaɪ́t/, etc.

In list C, {gn-}, if preceded by juncture, is mapped into {n} by the same rule that levels {kn-}, {pt-}, and {pn-} to {n}, {t}, and {n} (e.g. *knee*, *ptarmigan*, and *pneumonia*). That is, English phonotactics will not permit a sequence of two initial stops. (See Hill, 1958). If {gn} is not preceded by juncture, then it is mapped into {gn}. For example, *diagnosis*, *prognosis*, *agnostic*

{daɪæ}   {daɪægnósɪs}
        + {gnosɪs} →
{pro} +   {pragnósɪs}

{e} + {gnastɪk} → . . . . → {ægnástɪk}

This mapping for {gn} also applies to morpheme final {gn}, except that two classes of suffixes must be distinguished -- neutral and mutating. A base form before a neutral suffix behaves in the same way as it does before word juncture. The behavior of the base form before mutating suffixes, however, is generally different from the case cited above. Examples of neutral suffixes are (in their graphemic forms) ⟨-ing⟩ and ⟨ed⟩. Thus, /saɪ́n/, /saɪ́nɪŋ/, /saɪ́nd/. Mutating suffixes are forms like ⟨-al⟩ and ⟨-ify⟩ : /sɪ́gnəl/, /sɪ́gnɪfaɪ/.

Before word juncture or a neutral suffix, {gn} is mapped into {n}; otherwise, it is retained as {gn}. Thus

⟨sign⟩ → {sɪgn} + / → . . . /saɪ́n/

+ {-ɪŋ} → . . . /saɪ́nɪŋ/

+ {-ɪfaɪ} → . . . /sɪ́gnɪfaɪ̀/

The alternation of {ɪ} to {aɪ} in the example above follows from the change of the consonant environment from two units to one, as in malign - malignant: phlegm - phlegmatic: paradigm - paradigmatic: impugn - impugnable.

⟨rh⟩ has been treated traditionally as two units, the second of which is silent. While there are no theoretical reasons for rejecting this approach, the parallel clusters ⟨ch⟩, ⟨gh⟩, ⟨sh⟩, ⟨th⟩, which are undisputably single units, sway the decision for treating ⟨rh⟩ as a single unit. ⟨Wh⟩ is also treated as a single unit, but for different reasons than those used for ⟨ch⟩, ⟨gh⟩, etc. ⟨Wh⟩ generally represents the cluster /hw/ (in the dialect used here) except in *whole* and *whore*, where the ⟨w⟩ is an artifact and was never pronounced. If the Old English spelling for this cluster, ⟨hw⟩, had survived into modern English, we would not treat it as a single unit since the separate rules for ⟨h⟩ and ⟨w⟩ would account for the morphophonemic representation. The only other alternative for handling ⟨wh⟩ is to regularize the spelling of ⟨wh⟩ to ⟨hw⟩ before applying the mapping rules, but we have no other need for regularizing rules, and the creating of an entirely new class of rules is unwarranted where the existing system can handle the case in point.

It is crucial to distinguish between spelling units that function purely as *markers* and those that are *relational*. A marker serves solely to indicate the correspondences of other graphemes -- it has no proper morphophonemic correspondence itself, although for systemic purposes it can be mapped into zero. The final ⟨e⟩'s in *have*, *mate*, and *chance* are markers, although the marking functions they perform are distinct. The ⟨e⟩ in *have* preserves a graphotactic pattern since ⟨v⟩ is not allowed in final position in English words. In *mate*, the ⟨e⟩ marks the complex pronunciation of ⟨a⟩ (⟨a⟩ → {e} as opposed to the unmarked ⟨a⟩ → {æ} as in *mat*, (see Section 51) and in *chance* the ⟨e⟩ marks the correspondence ⟨c⟩ → {s} as opposed to ⟨c⟩ → {k}.

Numerous markers are employed in the current orthography, and for a proper understanding of spelling-to-sound correspondences, they must be distinguished from those units that are primarily relational -- that is, those units which have proper morphophonemic correspondences. Relational units are those units that appear as the first elements on the left-hand side of spelling-to-morphophoneme rules. Some relational units, like the ⟨i⟩ in *city* and the ⟨u⟩ in *argue* perform marking functions, but since their primary function is relational, they are classed as relational units.

In the traditional treatments of orthography (Hall, 1961), markers are not distinguished as such, but rather, are included as parts of grapheme clusters, thus leading to the notion of discontinuous clusters like *a . . . e* in *make*. Besides being extremely uneconomical and complicated, this method of analysis fails to emphasize the pure marking functions which are an integral part of the orthography.

As a final note, we will continue to use the term grapheme to refer to elements on the graphic level, although we do not consider the grapheme to be parallel to the phoneme in the sense of Hall (1961) or Pulgram (1951). We consider the spelling convention as a self-contained system and not merely a reflex of the phonemic inventory. Individual letters may or may not be functional units, e.g., ⟨t⟩ and ⟨h⟩ are two single graphemes, but a third single functional unit is ⟨th⟩, a cluster of two letters, In addition, spelling must be viewed as having morphophonemic correspondences, and therefore being more closely related to levels other than the phonemic one.

4.4 Selection of Phonemic Units

Characteristics of the phonemic transcriptions used in this study are described in our previous report, (Weir, 1964). For the most part these transcriptions are identical to a phonemicization of Kenyon and Knott's transcriptions (Kenyon and Knott, 1951) for American English. Following is a brief description of the phonemic system adopted here. The phonemic symbols employed follow closely those used by Kurath (Kurath, 1964).

Consonants

p			t		č	k	
b			d		ǰ	g	
	f	θ		s	š		h
	v	ð		z	ž		
m			n			ŋ	
		l	r				
					j	w	

Stressed Vowels

	Front	Central	Back	
High	ɪ i		ʊ u	aɪ
Mid	ɛ e	ə	o	au
Lower-mid	æ		ɔ	ɔɪ
Low				

The symbol /ə/ is used both for the stressed ([ʌ]) and the unstressed mid-central unrounded vowel; /aɪ, əʊ, ɔɪ/ are the only true diphthongs in this system: /i, e, u, o/

all have variants /ij, ej, uw, ow/, but for simplicity we prefer the single symbol representation. In words like *bird*, the retroflexed vowel which is symbolized by Kenyon and Knott as [ɝ] is here transcribed as /ər/. This is done simply for convenience. (While the acoustical evidence is not overwhelming, it does indicate that the syllabic peak in words like *bird* is not phonetically a combination of [ə] plus [r], but rather, a single vowel (Lehiste, 1964).

4.5 Segmentation

The first step in determining the pronunciation of a graphemic word -- that is, of any string of graphemes that occurs between blanks -- is to segment the word into its smallest meaningful graphemic units. These units, called graphemic allomorphs, then form the input to the spelling-to-morphophoneme rules. It is difficult to over-emphasize the importance of segmentation. Without this step, many of the regular mapping rules evaporate without a trace. Consider, as a start, the status of the rules for the morpheme final graphemic combination VOWEL + CONSONANT + ⟨e⟩. Without segmentation, forms like *notebook*, *rosebud*, *safety*, and *rarely* would no longer fall in the domain of these rules, but rather, in the domain of rules which would map the ⟨-e-⟩ in each of these words into a non-zero form.

Equally sensitive to morpheme boundaries are the rules for handling double consonants. For example, the difference in the pronunciations of the geminate clusters in *inner* and *unnatural* is due to the morpheme boundary between ⟨un⟩ and ⟨natural⟩, a difference that would not be recognized without first segmenting the bi-morphemic form.

Besides the recognition of morpheme boundaries, segmentation is also necessary for obtaining the correct graphemic clusters. The cluster ⟨ee⟩ as in *seen*, *feel*, and *meet*, for example, is mapped, with a few exceptions, into [i] (see Section 5.7). In no single morpheme is it ever mapped into more than one morphophoneme. Without segmentation, however, forms like *preempt* and *reenforce* would either be incorrectly handled, or would have to be listed as exceptions to the ⟨ee⟩ rule. This also would be the choice faced with forms like *whereat*, *doing*, *cooperate* and *coexist*, to name just a few, where the clusters ⟨ea⟩, ⟨oi⟩, ⟨oo⟩, and ⟨oe⟩ occur across morpheme boundaries. (The use of the diaeresis in forms like *coöperate* is an attempt to mark the proper units in such words.)

Further examples which demonstrate the need for segmentation can be evidence in almost any of the grapheme-to-morphophoneme rules, e.g., ⟨ng⟩ in finger vs. ⟨ng⟩ in singer; ⟨mb⟩ in cucumber vs. ⟨mb⟩ in climber; the ⟨ph⟩ in sophomore vs. ⟨ph⟩ in shepherd.

The simplest statement that can be made in favor of segmentation is that the recognition of morpheme boundaries is crucial for obtaining much of the regularity that exists in the grapheme-phoneme relationships. A second argument in its favor is economy. A form like love, for example, is an exception to the general vowel + consonant + final ⟨e⟩ rules. It therefore must be listed in the dictionary of exceptions. Without a segmenting process, we would also have to list loved, loves, lovely, loving, lover, lovers, lovable, lovingly, and lovelyness -- and the list does not stop with the exhaustion of the paradigms of love, but continues with all common compounds containing love -- lovesick, lovelorn, etc.

Segmentation requires more than drawing lines between graphemes. It requires in its complete form the recognition of all graphemic allomorphs, regardless of the graphemic alternations which may take place. The form facing, for examining, must be recognized as ⟨face⟩ + ⟨ing⟩, rather than ⟨fac⟩ + ⟨ing⟩, in order for the pronunciation of both ⟨a⟩ and ⟨c⟩ to be obtained correctly. Consider, as a parallel example, the graphemically irregular form ⟨arcing⟩. By analogy ⟨facing⟩ could become [fǽkɪŋ]. In the case of facing, therefore, we must recognize ⟨fac-⟩ as a graphemic varient of ⟨face⟩, while in arcing, we must recognize ⟨arc⟩ as the basic form and not as a varient of *⟨arce⟩.

In many cases, the orthographic rules found in desk dictionaries will correctly identify the graphemic allomorphs in a word. In cases like longer (comparative of long) vs. longer (agentive), form class information must be used for proper identification. In some cases, graphotactics may supply necessary information. A word that ends in ⟨-ous⟩, for example, almost certainly is not a form ending in ⟨-ou⟩ plus the noun plural (or third singular verb) marker ⟨s⟩, since ⟨ou⟩ does not occur in word final position [1], but rather ⟨ow⟩. Similarly, ⟨-ows⟩ does not occur in monomorphemic words, except in a few aberrant forms like gallows and bellows, which are both singular and plural.

In many cases the analyst must make what appears to be an arbitrary decision between base form and suffix. While we cannot at this time give a firm set of rules for all of English graphemic segmentation, we can show how such a decision was made in any one particular case. Following is an example with a discussion of alternative solutions. The choice to be made is the graphemic shape of the suffix in *gradual* -- ⟨-al⟩ vs. ⟨ual⟩.

A number of graphemic forms add a ⟨u⟩ before taking the adjectival and noun forming suffix ⟨-al⟩. For example,

grade	gradual	(the final ⟨e⟩ is automatically dropped before a vowel except when preceded by ⟨c⟩ or ⟨g⟩: see Section 4.3)
fact	factual	
rite	ritual	
intellect	intellectual	
act	actual	

In tabulating graphemic allomorphs a choice must be made between establishing an alternate base ending in ⟨u⟩, e.g., *fact*, *factu-*, or an alternate suffix, ⟨-ual⟩, that appears in place of ⟨-al⟩ after a selected list of forms. Whatever decision is made on the graphemic level must also be applied on the morphophonemic level. Thus, if the graphemic base of ⟨factual⟩ were ⟨factu-⟩, then {fækt} must be replaced by {fæktju-} on the morphophonemic level when suffixed by {-al}. And, alternately, if ⟨-ual⟩ were designated as the suffix, then {-al} must be replaced by {-jual} when preceded by forms like *fact*. Either decision requires the designation of the forms like *fact* which add ⟨u⟩ before the ⟨-al⟩ suffix.

The choice of the ⟨-ual⟩ suffix is attractive since it seems to require only a single alternate suffix, rather than an alternate base for each noun and verb. More convincing evidence, however, supports the alternate base approach. First, forms like *continual* and *virtual*, which end in ⟨-ual⟩ could not be treated as having a ⟨-ual⟩ suffix, since the ⟨u⟩ clearly belongs to the base forms *continue* and *virtue*. To set up *contin-* and *virt-* as base forms and ⟨-ue⟩, and ⟨-ual⟩ as suffixes is both unrealistic and overly burdensome. Second, if ⟨-ual⟩ were an alternate of ⟨-al⟩, ⟨-uate⟩ would have to be an alternate of ⟨-ate⟩ to account for such forms as *perpetuate*, *effectuate*, and *habituate*, and further, ⟨-uity⟩ of ⟨-ity⟩ to account for *perpetuity* and *annuity*. Clearly, this proliferation of alternate ⟨-u⟩ suffixes is not only undesirable, but also unrealistic in view of the distributional properties of ⟨-u-⟩ as presented above. Therefore, the alternate base forms will be employed here.

Assuming that we select two base forms for the items in question, then we can handle the morphophonemic alternations in two different ways. The first is to establish such morphophonemic forms as {grædju-} and {rɪtju-}, with the rule that before word juncture {ju} is dropped and the vowels {æ} and {ɪ} are changed to their complex alternates {e} and {aɪ} (see section 5.1). The alternate process is to use {gred} and {raɪt} as the base forms, and establish the rule that before {al}, the vowels take their simple alternates and a {ju} is added to the end of each base form if it does not already end in {ju}[2]. While the first method is the most appealing from a purely morphophonemic standpoint, it cannot be used in the graphemically based system since {grædju} and {rɪtju} cannot be derived from ⟨grade⟩ and ⟨rite⟩, except through rather suspicious gyrations and contortions. Therefore, the second process will be used here. The forms to which this process can be applied are listed in group A. The group B are those "forms which have no noun or verb alternate, "petrified forms" in Newman's terminology (Newman, 1942).

GROUP A

act	actual	convent	conventual
case	casual	rite	ritual
continue	continual	reside	residual
effect	effectual	concept	conceptual
fact	factual	sense	sensual
grade	gradual	spirit	spiritual
lingua	lingual	sex	sexual
intellect	intellectual	tact	tactual
habit	habitual	use	usual
event	eventual	vision	visual
		virtue	virtual

GROUP B

manual	(manufacture)
annual	(annals, annuity, anniversary)
individual	(individuate)
mutual	
perpetual	(perpetuate, perpetuity)
punctual	(punctate, punctuate)

4.6 Application of Rules on Various Levels

In many cases the choice of the level at which particular rules are applied is arbitrary. Consider for example, the rule that indicates whether ⟨c⟩ eventually becomes {s} or {k}. On the graphemic level this rule would be written:

1. ⟨c⟩ (--- i/y/e) → {s}

2. ⟨c⟩ (ELSE) → {k}

Since ⟨i⟩, ⟨y⟩, and ⟨e⟩ represent front vowels, the placement of this rule on the morphophonemic level allows greater elegance in that the rule there would be based upon features-non-low-frontness rather than upon a list of graphemes. (This could be avoided on the graphemic level by defining classes for vowel graphemes, viz. ⟨e,i,y⟩ and ⟨a,o,u⟩, that enter into the rules for ⟨c⟩ and ⟨g⟩. This possibility will be discussed shortly.)

Nevertheless, in exchange for increased elegance, the morphophonemic rule places two burdens upon the total system. The first is an increase in the number of morphophonemes, namely, adding {c}. In general terms, the rule in question then appears as

3. {c} + {front non-low vowel} → {s}

4. {c} (ELSE) → {k} [3]

Where {c}, an unknown quantity at this point, is derived from ⟨c⟩ by the rule

5. ⟨c⟩ (ALL) → {c}

{c} could be {s}, {k} or a new morphophoneme. {s} is an impossible solution, due to such forms as {su}, {sɔt} and {so}, which would become {ku}, {kɔt}, and {ko} by rules 3 and 4 above. The mappings would be

⟨sue⟩ → {sju} → {ku}
⟨sought⟩ → {sɔt} → {kɔt}
⟨so⟩ → {so} → {ko}

since initial ⟨s⟩ is always mapped into {s} (see previous report, page 37) and then by rules 3 or 4 above, with {s} replacing {c} on the left, {s} would be mapped into {k}. Only by distinguishing {s} derived from ⟨c⟩ from {s} derived from other sources could this problem be avoided. But to create a special {s} is to form a new morphophoneme, so the {s} solution must be eliminated. By the same reasoning {k} must also be eliminated. (cf. {kɪt}, {kɛpt} {keǧ}), thereby leaving a new morphophoneme as our only choice. This is the first burden.

The second burden arising from the adoption of rules 3 and 4 is that the morphophoneme {j} cannot appear after the morphophoneme derived from ⟨c⟩ until after rules 3 and 4 are applied. Consider the word social. The palatalization of {s} → {š} occurs before {j} + vowel (unstressed), (see Section 6.3) and therefore one way of handling this word is to map ⟨i⟩

directly into [j]. As desirable as this may be, it cannot be done if ⟨c⟩ is mapped invariably into a single morphophoneme [c] since this would yield [socjal] at the first morphophonemic level. By the application of rules 3 and 4 we would be stuck with [sokjal], and no amount of rule writing could extricate us from this position. We could not include [cj] in the list of palatalizable forms, since palatalization would then apply incorrectly to forms like [æcjurɪt] (from ⟨accurate⟩). For consistency, therefore, [j] cannot be obtained directly from a vowel grapheme, but only from a morphophoneme by mp-mp or mp-p rules.

The selection of rules 1 and 2 in preference to 3 and 4, while theoretically arbitrary, is encouraged by these systemic burdens which stem from the latter rule pair. Similarly, the rules for deriving [g] and [ǰ] from ⟨g⟩ will also be g-mp rules.

5. RESULTS I - Vowel Correspondences

The functional vowel spelling units, **are divided** into simple and compound classes on the basis of the number of graphemes in each unit. A simple unit is one which consists of a single grapheme. A compound unit consists of two or more graphemes. As arbitrary as this dichotomy appears, it is highly significant for the prediction of sound from spelling and reflects important differences in vowel patterning. Each simple vowel unit has two principal morphophonemic correspondents, both of which normally reduce to schwa with loss of stress. Compound vowels, on the other hand, commonly have only one regular morphophonemic correspondent, and this correspondent tends to retain its identity even with loss of stress. Furthermore, the simple units commonly occur before geminate consonant clusters (see Section 5.8) while the complex units rarely do.

The geminate consonant cluster influence is part of a more general pattern which has emerged from this work, namely that the simple vowel spellings before single consonants correspond most regularly to their simple morphophonemic correspondents, while before consonant clusters, to their complex correspondents. This pattern is described more fully in Section 5. .

5.1 Simple Vowel Units

The simple vowel units and their major morphophonemic correspondences are as follows

	complex	simple
⟨a⟩	{e}	{æ}
⟨e⟩	{i}	{ɛ}
⟨i/y⟩	{aɪ}	{ɪ}
⟨o⟩	{o}	{a}
⟨u⟩	{ju}	{ə̇}

While examples of many other vowel alternations can be cited, the alternations shown above account for the majority of the English morphophonemic vowel alternations

Examples

⟨a⟩

[e]	[æ]
sane	sanity
mendacious	mendacity
urbane	urbanity

⟨e⟩

[i]	[ɛ]
athlete	athletic
serene	serenity
obscene	obscenity

⟨i⟩

[aɪ]	[ɪ]
rise	risen
malign	malignant
decide	decision

⟨o⟩

[o]	[a]
verbose	verbosity
mediocre	mediocrity

⟨u⟩

[jù]	[ə]
reduce	reduction
produce	production

A discussion of the morphophonemic alternations based upon ⟨u⟩ is given in RESULTS, part 5.

5.2 Spelling to morphophonemic mappings

Besides occurring in predictable morphemic environments, (see Sections 6.1,6.2) the simple vowel alternates on the morphophonemic level are also predictable from their graphemic environments.

The most general rules for simple vowel mappings (see Section 5.1) are the following:

⟨V⟩ (--C+(l/r) +V) → [Vcomplex]
⟨V⟩ (--C +C/ ≠) → [Vsimple]

In expanded form these rules appear as follows (see Section 4.2:

Rule 1. ⟨V⟩ (--C + l + V) → {Vcomplex}
" 2. ⟨V⟩ (--C + r + V) → {Vcomplex}
" 3. ⟨V⟩ (--C + V) → {Vcomplex}
" 4. ⟨V⟩ (--C + C) → {Vsimple}
" 5. ⟨V⟩ (--C + ≠) → {Vsimple}

Examples

Rule	1	2	3	4	5
⟨a⟩	ladle	acre	canine	saddle	sat
⟨e⟩		zebra	median	antenna	set
⟨i⟩	idle	microbe	pilot	apostle	sit
⟨o⟩	noble	mediocre	vogue	cognate	sod
⟨u⟩	quadruple	lucre	dubious	supper	sub

In attempting to apply these rules, however, a number of other factors must be considered. The most important are the numerous minor patterns which modify the mappings obtained by these rules, e.g., the ⟨r⟩, ⟨l⟩, and {ʊ} patterns (Sections 5.4, 5.5, 5.6), and reduction with loss of stress. In addition, there are a large number of exceptions which do not fit into regular patterns, but must be handled as whole-word exceptions. The extent of regularity in this pattern will not be known until the entire spelling-to-sound mapping is completed. In the analysis of this pattern for stressed ⟨u⟩, the pattern was found to hold with high regularity. The two minor patterns which must be applied for ⟨u⟩, the ⟨r⟩ pattern and the ⟨u⟩ → {ʊ} pattern, are described in sections 5.4 and 5.8.

With these patterns considered, the only exceptions to the general rules (1-5 above) for ⟨u⟩ are the following:

sugar
umlaut

butte
fuchsia
truth
ruth

punish
usher
study
truculent

tumult
duchess
public

Of these exceptions, a number appear to fit into patterns which have not been fully analyzed yet. For example, in the environment ⟨-th + ⌿⟩, the simple vowels ⟨a, e, i/y⟩ pattern regularly, that is, correspond to their simple alternates {æ, ε, ɪ}, as in path, pith. In contrast to these, ⟨o⟩ and ⟨u⟩ correspond most regularly to their complex correspondents {o/ɔ} and {ju} in this environment e.g., both, broth, moth, truth. Butte is a recent French borrowing, sometimes spelled bute, which is a regular spelling for /bjút/, and duchess can probably be explained on the basis of the neutral suffix ⟨-ess⟩ (see Section 4.3).

Two regular sub-patterns can be derived from the general rules given above. These are the final ⟨e⟩ patterns and geminate consonant cluster patterns, which are described by the following rules:

a. ⟨V⟩ (+-C + e⌿) → {Vcomplex}
Final ⟨e⟩ rule.

b. ⟨V⟩ (--CiCi) → {Vsimple}
Geminate consonant rule.

A complete discussion of the final ⟨e⟩ patterns was included in our last report (Weir, 1964, p. 42-5). Shown below are some examples of these two patterns.

⟨a⟩		
	{e}	{æ}
	rate anal	rat annal(s)
⟨e⟩		
	{i}	{ε}
	mete Peter	met petter (one who pets)
⟨i⟩		
	{aɪ}	{ɪ}
	site diner	sit dinner

⟨o⟩

{o}	{a}
pope	pop
coma	comma

⟨u⟩

{ju}	{ə}
cute	cut
super	supper

5.3 Consonant influences

Cutting into the general vowel alternation patterns described above are three minor patterns: Vowel + ⟨r⟩, Vowel + ⟨l⟩ and {w} + Vowel. These minor patterns are not irregularities in any sense; they are regular patterns that interact predictably with the other vowel patterns. These patterns will be discussed in the following sections.

5.4 Vowel + ⟨r⟩ patterns

A summary of the morphophonemic correspondences of the simple vowels before graphemic ⟨r⟩ is shown below, followed by rules and examples for each unit. In parentheses following each morphophonemic unit is the unit that would be expected for the same environment with any other consonant except ⟨r⟩ (for ⟨l⟩, see Section 5.5).

	Environment		
VOWEL UNIT	--r + V + V/#	--r + V + C	--r + C/#
⟨a⟩	ɛ (e)	æ (æ)	a (æ)
⟨e⟩	ɪ (i)	ɛ (ɛ)	ə (ɛ)
⟨i/y⟩	aɪ (aɪ)	ɪ (ɪ)	ə (ɪ)
⟨o⟩	o/ɔ (o)	a/o (a)	ɔ/o (a)
⟨u⟩	jʊ (ju)	* (ə)	ə (ə)

*Defective position: only examples are urine and mural.

⟨a⟩

⟨ar⟩ + V + C → {ær}

arid
caravan
claret
charity
marital
parallel
parody
tariff

⟨ar⟩ + V + V/⌿ → {ɛr}

aquarium
beware
compare
malaria
nefarious
secretary
totalitarian
various

Exceptions:
Parent {ɛ/æ}
polaris {ɛ/æ}
transparent {ɛ/æ}
are {ar}

⟨ar⟩ + C/⌿ → {ar}

alarm
barter
carve
chart
garden
gargle
parcel
yard
bar
car
cigar
star

⟨e⟩

⟨er⟩ + V + C → {ɛr}

austerity
cherish
cleric
experiment
heresy
merit
peril
sheriff

⟨er⟩ + V + V/⌿ → {ɪr}

era
adhere
austere
cereal
criteria
exterior
here
imperial
sphere
zero

⟨er⟩ + C/⌿ → {ər}

erb
erst

⟨i⟩

⟨ir⟩ + V + C → {ɪr}

empiric
miracle
spirit
virile

⟨ir⟩ + V + V/ ⌿ → {aɪr}

ire
dire
fire
hire
wire

enquiry

iris
irony
siren
spiral
virus
tirade

⟨ir⟩ + C/ ∠ → {ər}

bird
whirl
girl

⟨o⟩

⟨or⟩ + V + C → {a/ɔr}

oracle
orange
orator
orifice
origin

moral
authority
foreign
forest
historic

⟨or⟩ + V + V/ ⌿ → {o/ɔr}

ore
orient
oriole
adore

arboreal
shore
glory
explore

moron
decorum
force
floral

Exceptions: borough
thorough

⟨or⟩ + C/ ⌿ → {ɔ/or}

or
orb
orchard
organ
adorn
cord
formula
fortify
normal
storm

Exceptions: attorney

⟨w⟩ + ⟨or⟩ → {ər}

whorl
word
worst
worm
worse
wort

⟨u⟩

⟨ur⟩ ᴛ V + V/ ⌿ → {jur}

cure
ordure
bureau
centurion
mature
procure
pure
secure
spurious

Exceptions: bury

⟨ur⟩ ᴛ C/ ⌿ → {ər}

cur
urge
urn
spur

5.5 Vowel + ⟨l⟩ patterns

The simple vowels ⟨a⟩ and ⟨o⟩ undergo various modifications when followed by ⟨l⟩. Geminate ⟨l⟩ in final position produces the correspondences ⟨a⟩ → {ɔ} and ⟨o⟩ → {o} where the normal correspondences would be ⟨a⟩ → {æ} and ⟨o⟩ → {a}. For example

{ɔ}		{æ}	
call	mall	calliper	mallard
fall	pall	fallacy	pallet
gall	tall	gallow	tallow
hall	stall	hallow	stallion

{o}		{a}	
boll	roll	bollard	rollick
poll	troll	pollen	trolley

An exception is doll; those words which have ⟨a⟩ preceded by ⟨w⟩ fall into a different pattern (see Section 5.6). That this environment does not influence the other simple vowels can be seen from the following examples.

bell	bellow	fill	filly
fell	fellow	bull	bullet
bill	billion	gull	gullet

The second type of influence exerted by ⟨l⟩ is through the medial and final clusters ⟨lk⟩, ⟨lm⟩ and ⟨lt⟩ and here the influence is only upon a preceding ⟨a⟩, whose regular correspondent in these environments is {ɔ} instead of {æ}. Thus,

balk
calk
chalk
stalk
talk
walk

balm
calm
palm
psalm
squalm
alms
almanac

basalt
exalt
halt
salt
malt
waltz

falter
almanac
alteration

Exceptions are palmetto, alkali, contralto, and altitude.

5.6 {w} + Vowel patterns

A preceding {w} causes the shift of {æ} to {a}, as in, for example, quantity, swamp, wand, watch and water.[4] There is a further tendency, especially before {l}, for {a} to shift to {ɔ}, e.g., want, wanton, walnut and warrior (see Kenyon, 1943). In walk, talk, tall, wall, etc., the regular spelling → morphophonemic correspondence is ⟨a⟩ → {ɔ}.

{w} also influences a succeeding {o} before {r} + consonant, by causing the shift {o} → {ə}, as in word, work, world, worm, worry, worse, worship, worst, wort, and worth. (Worn is an exception.)

5.7 Compound Vowel Units

The correspondence patterns for the compound vowel units are presented in the following pages. For convenience, the major patterns are presented before the minor patterns. In the ordering of rules, this should be reversed.

⟨ai⟩

Major patterns

1. ⟨aɪ⟩ → {e}   bait main wait

Stress reduction

1. {e} → {ɪ}   captain chaplain porcelain

Minor patterns

1. ⟨aɪ⟩ → {aɪ}
aisle

2. ⟨aɪ⟩ → {i}
plait

3. ⟨aɪ⟩ → {ɛ}
again against said

4. ⟨aɪ⟩ → {æ}
plaid plait

5. ⟨aɪ⟩ → ⟨a⟩ ᴛ ⟨i⟩
naive (see Section 4.2)

⟨ay⟩

Major patterns

1. ⟨ay⟩ → {e}   day always player

Stress reduction

1. {e} → {ɪ}
always --day

Minor patterns

1. ⟨ay⟩ → {i}
quay

2. ⟨ay⟩ → {aɪ}
aye bayou cayenne

⟨au⟩

Major patterns

1. ⟨au⟩ → [ɔ] trauma cause audience

2. stress reduction none

traumatic audacious authentic
inauspicious auspicious austere
causation autocracy

Minor patterns

1. ⟨au⟩ → [æ]
draught aunt laugh

2. ⟨au⟩ → [o]
chauffeur hautboy
chauvinist mauve

3. ⟨au⟩ → [e]
gauge

4. ⟨au⟩ → [au]
sauerkraut umlaut

⟨eu⟩

Major patterns

1. ⟨eu⟩ → [ju] feud eucharist neutron

2. stress reduction none
neutral - neutrality
feudal - feudalistic

Minor patterns

1. ⟨-eum⟩ → ⟨e⟩ + ⟨u⟩
museum

⟨aw⟩

Major Patterns

1. ⟨aw⟩ → [ɔ] claw raw saw

⟨aw⟩ major patterns (con't)

2. Stress reduction none

tómahàwk
jackdaw

Minor patterns - none

⟨ea⟩

Major Patterns

1. ⟨ea⟩ → [i] examples each reach breach

2. stress reduction none

Minor patterns

1. ⟨ea⟩ → [ɛ]

    a. before ⟨l + C⟩

    b. before ⟨-sure⟩

    c. in the following words:

bread
breadth
dead
dread
head
instead
meadow
ready

spread
thread
tread
treadle
breast
breath
deaf
death

endéavor
feather
weather
heaven
heavy
jealous
leather
leaven

peasant
pheasant
sweat
sweater
threat
treachery
weapon
weather
zealot

2. ⟨ea⟩ → [e]

bread
great
steak
yea

3. ⟨ea⟩ → ⟨e⟩ + ⟨a⟩

cereal
ocean
-eal (unstressed)
pageant
sergeant
vengeance

hydrangea
urea
ideal
-ean
area

cochlea
nausea
frachea
panacea
-eate
-eation

reagent
beatitude
genealogy
pyorrhea
theater
beatific

fealty
realty
chorea
diarrhea
real

<ee>

Major patterns

1. <ee> → [i]   eel bleed absentee
2. stress reduction
   [i] → [ɪ]   coffee committee levee

Minor patterns

1. <ee> → [ɪ]
   been breeches creek
2. <ee> → [e]
   matinee melee

<ei>

Major patterns

1. <ei> → [e]   reign surveillance veil
2. stress reduction   counterfeit foreign forfeit
   [e] → [ɪ]

Minor patterns

1. <ei> → <e> ↑ <ɪ>
   alneid athei- cuneiform
   albeit dei- protein
   thei- casein
2. <ei> → [ɛ]
   heifer
3. <ei> → [aɪ]
   height sleight (either) (neither)
   fahrenheit gneiss holstein
   kaleidoscope stein
4. <ei> → [i]
   con- {ceit (neither-either) caffein
   re- {ceive leisure seize
   de- sheik ceiling

⟨ey⟩

Major patterns

1. ⟨ey⟩ → [e] abeyance convey obey

2. stress reduction

   [e] → [ɪ] abbey donkey galley

Minor patterns

1. ⟨ey⟩ → [i]
   key

2. ⟨ey⟩ → [aɪ]
   eye geyser walleye

⟨ew⟩

Major patterns

1. ⟨ew⟩ → [ju] ewe pewter new

2. stress reduction none

Minor patterns

1. ⟨ew⟩ → [o]
   sew shew

⟨ie⟩

Major patterns

1. ⟨ie⟩ (F) (monosyllables) → [aɪ] die lie tie

2. ⟨ie⟩ (F) (ELSE) → [ɪ] calorie genie movie

3. ⟨ie⟩ (M) (-v,-f,-ld,-nd) → [i] achieve field grief

4. ⟨ie⟩ (M) (-nt,-ncV) → ⟨i⟩ + ⟨e⟩ client science

5. stress reduction:

   final [aɪ] → [ɪ] calorie coolie specie

⟨ie⟩ (con't)

Minor patterns

1. ⟨ie⟩ → [i]
diesel lien shriek spiel

2. ⟨ie⟩ → [ɛ]
friend

3. ⟨ie⟩ → [i]
lingerie

4. ⟨ie⟩ → [ɪ]
series

5. ⟨ie⟩ → ⟨i⟩ + ⟨e⟩

quiescence
medieval
acquiesce
requiem

sienna
fiesta
siesta
client

diet
quiet
science

⟨oi/oy⟩

Major patterns

1. ⟨oi/oy⟩ → [ɔɪ] boy join loiter

2. stress reduction none

Minor patterns

1. ⟨oi⟩ → [ə]
mademoiselle porpoise tortoise

2. ⟨oi⟩ → [ɪ]
chamois

3. ⟨oi⟩ → [wɑ]
valois

4. ⟨oy⟩ → [o]
coyote

⟨oa⟩

Major patterns

1. ⟨oa⟩ → [o] approach boast goal

2. stress reduction none

Minor patterns

1. ⟨oa⟩ → [ɔ]
broad

2. ⟨oa⟩ → ⟨o⟩ ↑ ⟨a⟩
boa protozọa oasis inchoate

⟨oe⟩

Major patterns

1. ⟨oe⟩ (F) → [o] doe hoe oboe

2. ⟨oe⟩ (M) → ⟨o⟩ ↑ ⟨e⟩ poẹt noel poem

stress reduction none

Minor patterns

1. ⟨oe⟩ → [u]
conoe shoe

2. ⟨oe⟩ → [i]
amoeba foetus phoenix supboena

⟨oo⟩

Major patterns

1. ⟨oo⟩ → [u]
boot broom proof tycoon

⟨oo⟩ major patterns (con't)

2. stress reduction none

Minor patterns

1. ⟨oo⟩ → (ʊ)
book
brook
cook
crook
foot
forsook
good
hook
look
mistook
took
rook
shook
soot
stood
took
wood
wool

2. ⟨oo⟩ → (ə)
blood
flood

3. ⟨oo⟩ → (o)
brooch

4. ⟨oo⟩ → (u)
pooh

⟨ou⟩

Major patterns

1. ⟨ou⟩ → (au)
abound
count
mountain
trousers

2. stress reduction none

Minor patterns

1. ⟨ou⟩ → (u)

accouter
bayou
boudoir
boulogne
bouquet
caribou
cougar
coupon
croup
ghoul
group
rendezvous
rouge
roulette
route
routine
soup
souvenir
stoup
toucan
troubadour
uncouth
vermouth
wound

2. ⟨ou⟩ → (ə)

(camouflage)
clough
country
couple
cousin
double
enough
joust
rough
slough
sough
touch
tough
trouble
young

3. ⟨ou⟩ → [u]
boulevard foulard would could should

4. ⟨ou⟩ → [o]
boulder mould poultice smoulder thorough
cantaloup moult shoulder soul

5. ⟨ou⟩ → [ɔ]
cough trough

6. ⟨ou⟩ → [a]
hough

⟨ow⟩

Major patterns

1. ⟨ow⟩ (I,M) → [au]
owl crown town vowel

2. ⟨ow⟩ (F) → [o]
arrow bow glow pillow

3. stress reduction none

Minor patterns

1. ⟨ow⟩ (F) → [au]
allow endow now row (brawl)
brow how plow sow
cow mow prow vow

2. ⟨ow⟩ (I,M) → [o]
bellows gallows own
bowl owe

3. ⟨owar⟩ → [or]
toward

⟨ue⟩

Major patterns

1. ⟨ue⟩ (F) (-gue) → [Ø]
analogue fatigue plague vogue

2. ⟨ue⟩ (F) (ELSE) → [ju]
blue glue issue tissue

⟨ue⟩ major patterns (con't)

3. ⟨ue⟩ (M) → ⟨ū⟩ + ⟨e⟩
cruel
duel
fluent
influence

4. stress reduction none

Minor patterns

1. ⟨ue⟩ → [ju]
argue

⟨uɪ⟩ Major and minor patterns

1. ⟨uɪ⟩ → [ju]

bruise
cruise
fruit
juice
nuisance
pursuit
recruit
suit
suitor

2. ⟨uɪ⟩ → [ɪ]

biscuit
build
circuit
conduit

3. ⟨uɪ⟩ (ELSE) → ⟨u⟩ + ⟨ɪ⟩

bruin
fluid
ruin
suicide

5.8 Vowel Spellings Before Geminate Consonate Clusters

Preceding vowel spellings

Spellings other than simple vowel spellings (a, e, i, y, o, u) are rare before geminate consonant clusters. The only intra-morpheme digraph spellings are the following:

chauffeur
bouillon
braille
sienna
puissance
trousseau
guess
silhouette

Mappings of preceding vowels

Preceding vowels are mapped into their simple vowel alternates (see Section 5.1) with the following exceptions:

⟨a⟩

1. ⟨a⟩ → [ɛ]
   marshmallow

2. ⟨a⟩ → [a]
   mamma

⟨o⟩

1. ⟨o⟩ → [ɔ]
   across   albatross   boss

2. ⟨o⟩ → [o]
   boggy   atoll   knoll
   swollen   roll   gross

⟨u⟩

1. ⟨u⟩ → [ju]
   butte

2. ⟨u⟩ → [ʊ]
   pudding   pussy

Examples of simple vowel alternations (these rules are not presented here in ordered form)

⟨a⟩

1. [æ] → [æ]

   abbess   flabby   grammar   callow   happen
   babbittry   accent   mammal   fallacy   battle
   cabbage   accept   apple   annals

2. [æ] ([w] ↑↑ [æ]) → [a] (see Section 5.6)

   wallop   squabble   waddle   swallow   wallet
   swaddle   twaddle   quaff   squall   wallop

⟨a⟩ (con't)

3. [ω] ([æ] + [l]) → [ɔ] (see Section 5.5)

ball
call
fall
small
wall

4. [æ] (unstressed) → [ə]

abbreviate
accommodate
paraffin
parallel
embassy
annoy

⟨e⟩

1. [ɛ] → [ɛ]

cheddar
beggar
egg
bellow
cellar
fellow
dilemma
kennel
tennis
lesson
message
success
spell
appellate

2. [ɛ] (unstressed) → [ɪ]

eccentric
efface
effect
effete

3. [ɛ] (unstressed) → [ə]

chancellor
excellent
intellect
satellite

⟨i⟩ ⟨y⟩

1. [ɪ] → [ɪ]

cribbage
wriggle
artillery
auxillary
bacillus
vanilla
willow
bill
symmetry
village
shrill
issue
blizzard

2. [ɪ] (unstressed) → [ə]

desiccate
fusillade
oscillate
syllabic
idyll

⟨o⟩

1. [a] → [a]

hobby
lobby
occupant
comma
odd
toboggan
toggle
commerce
collar
college
dollar
commit
hollow
trolley
accommodate
sonnet

⟨o⟩ (con't)

2. {a} ({a} + {f} + V / #) → {ɔ}

coffee coffin office off toffee
coffer offer doff scoff

3. {a} ({a} + {l} #) → {o}

swollen atoll roll knoll

4. {a} (unstressed) → {ə}

occasion corollary command committee
occult pollute commend

⟨u⟩

1. ⟨u⟩ (bilabial + u + ll / sh) → {u}

pullet bully bull pull
bulletin pulley full bush

6. RESULTS II - MORPHOPHONEMICS

6.1 Morphophonemic Alternations Based on ⟨u⟩.

Morphophonemic alternations based on stressed ⟨u⟩ are relatively uncommon in English, the most frequent being [ú] → [ə́]:

reduce	reduction
conduce	conduction
assume	assumption
presume	presumption

The conditions under which the alternation occurs are described in the spelling → morphophoneme rules for ⟨u⟩ (Section 5.2). Thus, ⟨u⟩ in the environment ⟨ --Ce/⟩ is mapped to [ju][5], and ⟨u⟩ in the environment (--C_1C_2-) is mapped to [ə] (with the limitations imposed by the minor patterns). Therefore, the only conditions under which we anticipate a vowel alternation is when the succeeding consonant environment changes from a single consonant to a cluster, or vice versa. Unstressed [u], on the other hand, generally does not alternate morphophonemically with unstressed [ə], but rather, remains as [u]. Thus,

usurer	usurious
utilize	utility
compute	computation
execute	execution

6.2 Morphophonemic Alternations based on ⟨a,e,i,o⟩

The morphophonemic alternations based on the simple vowel spellings ⟨a⟩, ⟨e⟩, ⟨i⟩ and ⟨o⟩ are more difficult to predict than those based upon ⟨u⟩, and require further analysis. Several patterns based upon suffixes, however, are obvious. These are listed below.

1. ⟨--ity⟩ : complex → simple

   ⟨a⟩ : [e] → [æ]

humane	sane	humanity	sanity
profane	urbane	profanity	urbanity

⟨e⟩ : [i] → [ɛ]

obscene	obscenity
serene	serenity
extreme	extremity
supreme	supremity

⟨i⟩ : [aɪ] → [ɪ]

divine	divinity
asinine	asininity
senile	senility
malign	malignity

⟨o⟩ : [o] → [a]

verbose	verbosity
mediocre	mediocrity
precocious	precocity
frivolous	frivolity

2. ⟨-ic⟩ : complex → simple

⟨a⟩ : [e] → [æ]

angel	angelic
state	static

⟨e⟩ : [i] → [ɛ]

athlete	athletic
meter	metric
hygiene	hygienic

⟨i⟩ : [aɪ] → [ɪ]

mime	mimic
cycle	cyclic
paralyze	paralytic

⟨o⟩ : [o] → [a]

cone	conic
phone	phonic
neurosis	neurotic

3. ⟨-ion⟩

⟨a⟩ : [e] → [æ]

compare	comparison	(see Section 5.4 for vowel + ⟨r⟩ rules)

⟨e⟩ : [i] → [ɛ]

discrete	discretion
convene	convention
concede	concession

⟨i⟩ : [aɪ] → [ɪ]

collide	collision
provide	provision
divide	division
decide	decision

6.3 Palatalization

The process of palatalization is the source of many so-called irregularities in spelling-to-sound correspondences. Involved are the following spellings:

⟨s⟩ treasure, mission

⟨z⟩ axure, seizure

⟨t⟩ capitulate, nation[6]

⟨d⟩ arduous, schedule

⟨x⟩ luxury, complexion

Palatalization in English phonology refers to the sound changes

[sj] → [š]

[zj] → [ž]

[tj] → [č]

[dj] → [ǰ]

which Jespersen described as assibilation.

> "Under this name it is convenient here to comprise two changes, /sj/ and /zj/[ʃ, ʒ], and /tj/ and /dj/ > [tʃ, dʒ]. In the first, we have a sort of complete assimilation of the two sounds. In the second change, the off-glide from the more or less palatalized stop /t, d/ has developed into the sibilant, which has in most cases absorbed the following /j/."
>
> (Jespersen, 1961, p. 341)

Kenyon (1943, p. 135), in what is probably the best summary to be found of the phonetics of this process, describes two phonetic tendencies which lead to palatalization. The first is the shift of unaccented [ɪ] before another vowel to [j], so that the number of syllables in the word is reduced by one. Then, through assimilation, the changes [sj, zj, tj, dj] → [š, ž, č, ǰ] occur.

The palatalizing [j] is derived from several independent sources in the descriptive model adopted here. In creature, for example, ⟨u⟩ is mapped directly into [ju] (see Section 5.2); in cordial, however, ⟨i⟩ is mapped first into [ɪ], and then unstressed [ɪ] + vowel becomes j + vowel (with some exceptions which have not been fully described yet).

Palatalization generally takes place before an unstressed vowel: compare, for example, the stress on ⟨u⟩ in the following lists:

Palatalized	Unpalatalized
credulous	credulity
cynosure	pursuit
capitulate	presume
schedule	importune
assiduous	assiduity
treasure	institute

Morphophonemic rules for Palatalization

1. [sj] + $\underline{V}$ → [š] + $\underline{V}$

Examples

Graphemic	mp1	mp2	mp 3
nation	nesɪon	nésjən	néšən
social	sosɪal	sósjəl	sóšəl

examples (con't)

Graphemic	mp1	mp2	mp3
tissue	tɪssju	tɪ́sju	tɪ́šu
erasure	ɪresjur	ɪrésjur	ɪréšur
glacier	glesɪɛr	glésjər	gléšər
cautious	kɔsɪus	kɔ́sjəs	kɔ́šəs
luxury	ljuksjurɪ	lóksjurɪ	lókšurɪ

Exceptions

sure sugar

2. (zj) + V → (ž) V

Graphemic	mp1	mp2	mp3
abrasion	æbrezɪon	əbrézjən	əbréžən
measure	mɛsjur	mɛ́zjər	mɛ́žər
osier	osɪɛr	ózjər	óžər
visual	vɪsjuæl	vɪ́zjuəl	vɪ́žuəl
equation	ɪkwesɪon	ɪkwézjən	ɪkwézən
azure	æzjur	ǽzjər	ǽžər
scission	sɪzɪon	sɪ́zjən	sɪ́žən

3. (tj) + V → (c) + V

Graphemic	mp1	mp2	mp3
creature	kritjur	krɪ́tjər	krɪ́c̃ər
capitulate	kepɪtjulet	kəpɪ́tjulèt	kəpɪ́čulèt
righteous	raɪtɪus	raɪ́tjəs	raɪ́čəs
virtue	vɪrtju	və́rtju	və́rču

Exceptions

mature

4. $(dj) + \underline{V} \rightarrow (j) + \underline{V}$

Graphemic	mp1	mp2	mp3
arduous	ærdjuus	árdjuəs	árǰuəs
procedure	prosidjur	prosídjər	prosíǰər
cordial	kordɪal	kórdjəl	kórǰəl
graduate	grædjuet	grǽdjuɪt	grǽǰuɪt

Exceptions

produce

To account for the palatalizations, the following rules have been adopted, and must be applied in the order shown:

1. grapheme-to-morphophoneme rules
2. stress placement rules
3. palatalization of (sj, zj, tj, dj) before unstressed (u). (also, of *sugar*, *sure*, *mature*)
4. depalatalization of *produce*
5. elision of (j) before (u) except in syllable initial position and after (p, b, k, g, f, v, m, h, hw).
6. vowel reduction rules

Summary Table

1. stress placement

2. $$\left(\begin{matrix} s \\ z \\ t \\ d \end{matrix}\right) + (ju)\ \text{(unstressed)} \rightarrow \left(\begin{matrix} s \\ z \\ c \\ j \end{matrix}\right) + (u)$$

3. (sju) (súgar, súre) → (sǔ)

4. (tju) (matúre) → (ču)
5. (ǰu) (próduce) → (dju)
6. (ju) (syll. initial and after p/b/k/g/f/v/m/h/hw) → (ju)
7. (ju) (ELSE) → (u)
8. vowel reduction

7. CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Conclusions and implications

The results presented in this Report contain a number of implications for the teaching of reading. We hope to have demonstrated above all that simple grapheme-to-phoneme correlations are not only unproductive for the prediction of sound from spelling, but also are in conflict with the underlying system of the orthography. If the function of the teaching of reading is to establish productive habits which relate to the underlying patterns of the orthography rather than to base instruction on statistical correlations, then both morphology and syntax must be considered in the development of reading materials. This should not be construed as a suggestion to teach morphology and syntax in the first three or four grades where reading is normally taught, but rather as a recommendation for the selection and arrangement of words to be used in the design of teaching materials. We know that the child entering the primary grades has a good command of the basic morphological and syntactic patterns of his native language. To teach, for example, the pronunciations of hen, cat, match, and also hens, cats, matches as whole units is superfluous. The child has already learned the correct plural allomorph to be used with each stem. However, what he has to learn is the graphemic shapes of the noun plural marker so that he does not confuse such pairs as ⟨hens⟩ and ⟨hence⟩ in reading.

Some work still remains to be done before the material presented in this Report can be adapted to the teaching of reading. Some general notions, however, can be advanced at present. The most important one is that the major emphasis in teaching the relationship between spelling and sound should center on the spelling-to-morphophoneme patterns. These represent totally new habits which must be obtained in order to read; the morphemic and syntactic patterns are, in general, already part of the child's language habits. The spelling-to-morphophoneme patterns should not be viewed as rules to teach as such, but rather as indicators of regularly and irregularly spelled words, that is, of words which have high transfer value and words which have low or negative transfer value for reading of other words. Obviously, words which are included in rules (e.g., ⟨ee⟩ (been) → [ɪ]) have low transfer value because they contain either exceptions to general patterns or rare and mostly unproductive correspondences.

The traditional view of spelling recognizes only one level of graphemic units, namely, the 26 letters of the alphabet, which are combined in various ways to correspond to phonemes.

In our research we have found that at least two basic distinctions are built into the orthography. The first is the distinction between relational units and markers, the other between simple and compound units. We feel that these distinctions are important for the teaching of reading and should be considered in the design of reading materials. Markers are an integral part of the English orthography; they are used specifically to point out the correspondences of other spelling units and do not, themselves, correspond to sounds.

Simple and compound spelling units, especially in the vowel spellings, fit into entirely different correspondence patterns. To neglect this distinction is to neglect much of the patterning in the spelling-to-sound relationship. In short, we suggest that the entire graphemic basis of spelling, down to even the term "grapheme", be reconsidered in light of the data presented in our Reports. While we cannot predict the utility of our approach for the teaching of reading, we do know that a higher degree of patterning exists on this level than has been considered in the past and that this patterning is important for the prediction of sound from spelling.

SUGGESTIONS FOR FURTHER RESEARCH

To continue the work reported here, we suggest investigations into the following areas:

I Graphotactics

A number of attempts have been made in recent years to systematize English graphotactics or to evolve theories of graphemics which include treatments of graphotactics (Hamp, 1959; Crossland, 1957; Hall, 1964). None of these works, however has treated English graphotactics as it relates to morphophonemics. We consider this area crucial to the improvement of reading instruction. The graphemic alternations which relate to suffixation are one area of concern. Another area concerns the graphemic variants on the order of ⟨au/aw⟩, ⟨oi/oy⟩, ⟨ou/ow⟩ -- the question being the distribution of the variants and what patterns can be found in the irregularities. Other features to investigate are the following.

1. The patterning of final ⟨e⟩ after ⟨c⟩ and ⟨g⟩.

2. The relation of digraph spellings like ⟨ee⟩, ⟨ea⟩ and ⟨au⟩ to morphophonemic alternations. (Our evidence indicates, for example, that while ⟨ee⟩ and ⟨e⟩ can both correspond to the morphophoneme {i}, only {i} derived from ⟨e⟩ shows the alternation /i/ - /ɛ/. While this is not relevant for a linguistic description of English phonology, it may be germane to the teaching of reading.)

3. The validity of the orthographic rules which are found in most dictionaries and which invariably become dogma in most classrooms. We believe that the systematic application of our concepts of marker vs. functional unit will yield a more meaningful set of rules.

4. The size of graphemic units to be used in rules for predicting pronunciation. Contrary to popular notions, we find that initial "⟨rh⟩ should not be considered as two units with a so-called "silent h", but rather as a single unit, parallel to ⟨ch⟩, ⟨th⟩, ⟨sh⟩, etc. Likewise, we find that final ⟨ng⟩ should not be considered as a single unit, but rather as two units. Quite general rules for predicting the pronunciations of ⟨n⟩ and of ⟨g⟩ will account for the various pronunciations of words like long, longer (comparative), longer (n), and finger.

II. Suffixation:

Suffixation is a highly productive process in English and one which is important to the teaching of reading. Much of the regularity that we find in spelling-to-sound relationships comes from the ability to recognize suffixes from their graphemic forms and to predict the morphophonemic alternations which they induce. This topic was partially explored from a linguistic standpoint by Stanley Newman in 1948 and from the educational standpoint by E.L. Thorndike in 1941. Little research of English suffixation has been published since then, although various language research groups have recognized the importance of suffixation in English. (Kingdon, 1958).

The first area of investigation in suffixation is the graphemic level. This includes the graphemic form of the suffix and the graphemic alternations induced in the stem. The second area concerns the effect of the suffix on the stress pattern of the stem and the degree of stress required by the suffix itself. The third area covers the segmental morphophonemic alternations which are induced by suffixation.

III. Morphophonemics:

Using the orthography as a point of departure, the principal English stressed vowel alternations can be arranged in the following pattern (see Section 5.1):

grapheme	complex alternate	simple alternate
⟨a⟩	/e/	/æ/
⟨e⟩	/i/	/ɛ/
⟨i⟩	/aɪ/	/ɪ/
⟨o⟩	/o/	/a/
⟨u⟩	/ju/	/ʌ/

The relationship of these morphophonemic alternations to patterns which occur in minimal phonemic pairs according to regular graphemic conditions is one object of the research proposed here. Compare, for example, the alternations above to those shown in Section 5.1 which are conditioned by final ⟨e⟩ _vs_. no final ⟨e⟩ and single succeeding consonant _vs_. succeeding geminate consonant cluster.

IV. Functional Load

Functional load of a phoneme is generally expressed as some statistical measure of the utterance-separating function of a phoneme. While this may be an interesting measure for some purposes, we feel that a more significant functional load measure can be computed for teaching reading. Our intentions are to consider not only the frequency factor, but also the alternation patterns which a phoneme or grapheme fits. In a sense, this will measure its degree of membership in the regular phonemic or graphemic classes. The phoneme /ɔɪ/, for example, may occur with a frequency equal to that of certain consonants, yet /ɔɪ/ rarely fits into alternation patterns. It is, in a sense, isolated from the core of the phonemic system. This is one of the variables which we want to include in a functional load analysis.

V. Reading Applications

The results of the work reported here suggest a number of possible investigations of reading habits. Starting with the spelling level, the first concern should be to determine the spelling units which the mature reader recognizes. Does, for example, the functional unit - marker dichotomy discussed in Section 4.3 function in the reading process? If it does, then the common reading notion of scanning letter-by-letter from left to right is erroneous and may impede the acquisition of reading skills.

Phonemic alternations based upon simple vowel spellings (see Section 5.1) occur frequently: does the mature reader recognize these alternations and if so, should the beginning reader be taught to do so?

Morphemic factors are important for the prediction of sound from spelling. How many of the morphemic factors which are included in spelling-to-sound rules described here also play an integral part in the actual reading process? The pronunciation of morpheme final ⟨ng⟩, for example, depends upon the following morpheme: if it is the regular comparative or superlative suffix, then the ⟨g⟩ is eventually mapped into /g/; otherwise, it is mapped into zero. Would a reader follow this rule in pronouncing synthetic words with ⟨ng⟩ spellings?

These, in our opinion, are some of the principal areas where further research is essential in order to provide a sound basis for the teaching of reading.

APPENDIX A

Computer Programs

TITLE: VOCALE

ENTRY POINTS: VOCALE

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: PROCESS, OUTPUT

PURPOSE: To buffer input for routine PROCESS and control the main program processing.

INPUT: Six word standard dictionary records on unit 5.

OUTPUT:
(1) Six word records in words 61-66 of common block LARYNX.
(2) EOF indicator in word two of common block GLOTTIS.

ERROR STOPS: None

TITLE:	FREQ
ENTRY POINTS:	FREQ
SOURCE LANGUAGE:	CODAP1
EXTERNAL SYMBOLS:	None
PURPOSE:	To replace characters 21-24 in the standard dictionary record with characters 41-44.
INPUT:	Standard dictionary record in words 61-66 of common block LARYNX.
OUTPUT:	Modified input record in same location
ERROR STOPS:	None

TITLE: PALAVER

ENTRY POINTS: PROCESS

SOURCE LANGUAGE: CODAP1

EXTERNAL SYMBOLS: MOVES ≠, COMSS ≠, COMSA ≠, GETWS ≠, PUTWS ≠

PURPOSE: To form grapheme-phoneme correspondences.

INPUT: Standard dictionary records in words 61-66 of common block LARYNX.

OUTPUT:
(1) Length of correspondence table in word one of common block LARYNX.
(2) Grapheme-phoneme correspondences in words 2-60 of same block.
(3) Error indicator in word 67 of same block
(4) Modified dictionary record in same location as in input.

ERROR STOPS: None

TITLE: OUTPUT

ENTRY POINTS: OUTPUT

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: FREQ, RIGHT

PURPOSE: (1) To form five-word logical records for sorting; record structure is as follows:

Character	
1-8	Grapheme cluster, right justified
9-15	Phoneme cluster, right justified
16	Position (1= initial, 2= medial, 3=final)
17-38	Spelling, left justified
39-40	Frequency

(2) To write error records on unit 7. If an error occurs in the correspondence forming program, the entire input dictionary record is output to unit 7.

INPUT:

(1) Length of correspondence table in word 1 of common block LARYNX.

(2) Grapheme-phoneme correspondences in words 2-60 of same block.

(3) Input dictionary record in words 61-66 of same block.

(4) Error indicator in word 67 of same block.

(5) EOF indicator in word 2 of common block GLOTTIS.

OUTPUT:	(1) 1000 word records in the first 1000 words of the common block NASAL. (2) Error records on Unit 7 (3) The total number of words filled in the 1000 word output array in word one of common block GLOTTIS.
ERROR STOPS:	None
NOTES:	When the EOF flag is set by the calling routine, OUTPUT fills all unfilled words in the output array, calls RIGHT, writes an EOF mark on unit 6, and exits to the monitor system.

TITLE: RIGHT

ENTRY POINT: RIGHT

SOURCE LANGUAGE: FORTRAN - 63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To buffer out 1000 word physical records for sorting.

INPUT: 1000 word record in the first 1000 words of common block NASAL.

OUTPUT: 1000 word records on unit 6

ERROR STOPS: A-Register

22 EOT detected during last write operation. Mount new tape on 6 and proceed.

33 Write error detected during last write operation. Restarting will cause another write attempt.

TITLE: BAKWRDS

ENTRY POINTS: BAKWRDS

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: BACKOUT, TERMINAL1

PURPOSE: To buffer in standard, blocked dictionary records and deblock them.

INPUT: Standard blocked dictionary records on unit 6.

OUTPUT: Seven word logical records in the first seven words of common block KCAB.

ERROR STOPS: A-Register

1 EOF on first read
2 read error on first read
3 read error in reading into MA
4 read error in reading into LA

NOTES: If the first word of a logical record is blank, seven words are skipped.

TITLE: BACKOUT

ENTRY POINTS: BACKOUT

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To reverse the spelling of input records and left justify the reverse field, beginning with the last character of the forward spelling.

INPUT: Seven word logical records in the first seven words of common block KCAB.

OUTPUT: 1000 word physical records on unit 7 with the following logical record structure:

Character	
1 - 20	Reversed spelling
21 - 24	blank
25 - 80	Input record

ERROR STOPS: A - Register

23	EOT or write error on last output

TITLE: TERMNAL1

ENTRY POINTS: TERMNAL1

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To terminate program BAKWRDS by

(1) filling unused words in the current buffer with blanks

(2) writing out the current buffer on unit 6

(3) writing an end of file mark on unit 6

(4) exiting to the monitor

INPUT: NONE

OUTPUT:

(1) current buffer on unit 6, followed by an end of file mark

(2) END OF OUTPUT on standard output unit

ERROR STOPS:

A - Register

55 EOT or write error on last write in BACKOUT

10 EOT or write error on writing out current buffer

TITLE: BLK200

ENTRY POINTS: BLK200

SOURCE LANGUAGE: FORTRAN 63/1604

EXTERNAL SYMBOLS: TBLOCK1

PURPOSE:
(1) To buffer in records for TBLOCK1
(2) To terminate blocking and write out the last blocked record

INPUT: Standard unblocked dictionary records on unit 6

OUTPUT:
(1) Seven word records in words 701-707 of common block A1
(2) If last blocked record was not filled by the last logical record then the unfilled words are filled with blanks and the record written on unit 7
(3) End of file on 7
(4) END OF BLOCKING on the standard output unit

ERROR STOPS: A-Register
30 EOF on first read
40 Read error on first read
31 EOF in second read
32 Read error in second read
33 Read error in reading into MA
34 Read error in reading into LA
55 EOT or write error on last output to unit 7

TITLE: TBLOCK1

ENTRY POINTS: TBLOCK1

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: SHIFT6

PURPOSE: To block seven-word dictionary records into 700 word blocks. Each logical record terminates with a 32_8 in character 56

INPUT: Seven word records in words 701-707 of common block A1

OUTPUT: 700 word physical records on unit 7

ERROR STOPS:

A - Register

77 Buffer exceeds 700 words

TITLE:	SHIFT6
ENTRY POINTS:	SHIFT6
SOURCE LANGUAGE:	CODAP1
EXTERNAL SYMBOLS:	None
PURPOSE:	To insert record mark (32_8) in character 56 of the input records. The record mark is added to the right end and the left most character is truncated
INPUT:	Seven word records in words 701-707 of common block A1
OUTPUT:	Same as input with record mark inserted
ERROR STOPS:	None

TITLE: LISTFIV

ENTRY POINTS: LISTFIV

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: TEST

PURPOSE: To buffer in records for TEST

INPUT: Unblocked standard dictionary records on unit 6

OUTPUT:

(1) Seven word records in arrays I and K. The first word address is the only parameter in the call to TEST

(2) End of file mark on unit 7at end of processing

(3) LISTING COMPLETED and total word count on standard output unit at end of processing

ERROR STOPS:

A-Register

33 EOF detected in first read operation

77 Read error in last read into I.

11 Read error in last read into K

NOTES: Units 6 and 7 are rewound before the routine exits to the monitor system

TITLE: TEST

ENTRY POINTS: TEST

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To select and list dictionary entries with frequency numbers ≤ 5

INPUT: Address of first word of dictionary record in input parameter LL

OUTPUT:
(1) Dictionary entries in seven word physical records on unit 7
(2) Total number of printed records in first word of common block POK

ERROR STOPS: A-Register
4 EOT detected on last write operation

NAME: UPDATE2

ENTRY POINTS: UPDATE2

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: UPDATE3, TERMINAL3

PURPOSE: To double buffer input for UPDATE3

INPUT:

1. 700 word logical records on unit 6
2. Correction records on unit 50. Only the first 64 characters of each record are read.

OUTPUT:

1. Seven word logical records in the first seven words of COMMON block KCAB
2. The first correction record in the first eight words of common block MAJ. The correction record is read with the format (6A8, 2I8). This is the only correction record read by this routine.

ERROR STOPS: A-Register

1 EOF in first record

2 Parity or buffer length error in first record

3 Parity or buffer length error in last record read into array MA

4 Parity or buffer length error in last record read into array LA

NOTES:

1. Any logical record whose first word consists of eight blank characters is skipped.
2. On the first EOF, TERMINAL is called. The program exits to the monitor system on return from TERMINAL

NAME: UPDATE3

ENTRY POINTS: UPDATE3

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: TBLOCK, SHIFTR, SHIFTL

PURPOSE: To delete, replace, or add records to the dictionary file.

INPUT:

1. Standard dictionary format records in the first seven words of common block KCAB
2. Correction records on unit 50. Records are read with the format (6A8, 2I8)

Correction card format is as follows:

Col.	
1-20	spelling
21-40	pronounciation
41-42	frequency
52-56	code number
64	correction type

1 delete
2 replace
3 insert

OUTPUT: Standard dictionary format records in the first seven words of common block KCAB

ERROR STOPS: None

NOTES: The correction card code is compared to dictionary codes until an equality is found. The action implied by col. 64 is then taken. The next correction card is read and its code compared to the code of the last correction card. If they are equal, the last card read is inserted next in the dictionary. This process is repeated with succeeding correction cards until an unequal result is found. Then the entire process is repeated, starting with the next dictionary record.

If a correction card code is less than the current entry code, the card is listed on the standard output and a new card is read.

NAME: TERMNAL3

ENTRY POINTS: TERMNAL3

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To terminate UPDATE2

ROUTINES CALLED: NONE

INPUT:

1. Dictionary records in the first 700 words of common block A1
2. The last correction card in the first seven words of common block KCAB

OUTPUT:

1. The last physical dictionary record on unit 7 if the record has fewer than 100 logical records.
2. The last correction card on unit 51

ERROR STOPS: A - Register

10 EOF, parity error, or buffer length error on last output to unit 7

NOTES: If less than 100 logical records are to be output, the remaining records are filled with blanks. An EOF mark is written after the last record on unit 7

NAME: TBLOCK

ENTRY POINTS: TBLOCK

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: SHIFT7

PURPOSE: To block output for UPDATE3 and buffer out.

INPUT: Seven word logical records (standard dictionary format) in the first seven words of common block KCAB

OUTPUT: 700-word blocked records (standard dictionary format) on unit 7

ERROR STOPS: A - Register

77 Block array index> 700

NAME: SHIFT7

ENTRY POINTS: SHIFT7

SOURCE LANGUAGE: CODAP1

EXTERNAL SYMBOLS: None

PURPOSE: To shift the last eight characters in a logical dictionary record left one character and add an end of record character (32_8) on the right.

INPUT: Seven word record in the first seven words of common block KCAB

OUTPUT: Seven word record in the first seven words of common block KCAB. The last word is as follows:

Character	
1-7	Same as input characters 2-8
8	32_8

ERROR STOPS: None

TITLE: SPELLING

ENTRY POINTS: SPELLING

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: SORTLYST, RAITOUT, TABOUT

PURPOSE:
(1) To buffer in the sorted grapheme-phoneme records.
(2) To terminate the tabulation and word list output.

INPUT: 1000 word logical records on unit 5

OUTPUT:
(1) 1000 word logical records in the first 1000 words of common block NASAL
(2) UNIT 6 } initial heading
UNIT 7 } and end of listing comment.
(3) An EOF mark on UNIT 6 after end of listing comment.

ERROR STOPS: (all on unit 5)

A - Register
1 EOF in first record
or
2 Parity/buffer error in first record
3 EOF in second record
4 Parity or buffer error in second record
5 Parity or buffer error in last read into LBUF
6 Parity or buffer error in last read into KBUF

NOTES:
(1) Program terminates on first end of file sensed on Unit 5
(2) Unit 56 is rewound before input or output begins.

TITLE: SORTLYST

ENTRY POINTS: SORTLYST

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: RAITOUT, TABOUT, DECOYD, MONOLYST, MYTE

PURPOSE: To deblock the output from SPELLING and pass only graphic monosyllable records for tabulation and listing.

INPUT: 1000 word records in the first 1000 words of common block NASAL. Logical records are five words in length and have the following structure (BCD characters):

Character	
1	V or C
2-6	grapheme cluster, left justified
7-8	blank
9	position (1,2,3 for initial, medial, final)
10-14	phoneme cluster, left justified
15-16	blank
17-36	spelling, left justified
37-38	frequency
39-40	blank

OUTPUT: (1) Starting position of a five word logical record in the second word of common block K9

(2) Headings on units 6 and 7 for the first vowel tabulation and the first vowel word list.

ERROR STOPS: NONE

NOTES:

(1) Grapheme clusters must begin with a grapheme in the range $33_8 \le G \le 71_8$ and not be 40_8

(2) Only the graphemes ⟨A, E, I, O, U⟩ are classed as vowels. Only one vowel cluster of one or two vowels may appear in a monosyllable. Final ⟨E⟩ is classed as a vowel cluster.

TITLE: MONOLYST

ENTRY POINTS: MONOLYST

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To control tabulations and word lists for program SPELLING

INPUT:
(1) A 1000 word record in the first 1000 words of common block NASAL
(2) The first word index for the current five word logical record in the second word in common block K9

OUTPUT:
(1) The current grapheme and phoneme clusters and the postion in the first three words of common block UVULA
(2) The spellings of words for each correlation in common block PLEX

ERROR STOPS: None

TITLE: DECOYD

ENTRY POINTS: DECOYD

SOURCE LANGUAGE: CODAP1

EXTERNAL SYMBOLS: None

PURPOSE: To unpack the spelling of a word and store it one character per word, right justified, with zero fill.

INPUT: The spelling of the word in the first 10 words of common block K8

OUTPUT: The first 20 characters of the spelling in words 12-31 of common block K8

ERROR STOPS: None

TITLE: RAITOUT

ENTRY POINTS: RAITOUT

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To output the word lists for program SPELLING

INPUT:
(1) The current grapheme and phoneme clusters and position code in common block UVULA
(2) The word list in common block PLEX

OUTPUT: Headings and word lists on Unit 6

ERROR STOPS: None

TITLE: UPKONT

ENTRY POINTS: UPKONT

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To count the number of occurrences of different phoneme clusters for a grapheme cluster, compute statistics and totals for each and output the results for printing.

INPUT: Grapheme and phoneme clusters and position in Common block UVULA

OUTPUT: Headings and statistics on Unit 7

ERROR STOPS: None

TITLE: MYTE

ENTRY POINTS: MYTE

SOURCE LANGUAGE: CODAP1

EXTERNAL SYMBOLS: None

PURPOSE: To extract a six-bit byte from a word and return it, right justified with zero fill, in the A register.

INPUT: None

OUTPUT: The designated byte in the A-register

ERROR STOPS: None

NOTES: The byte position 0-7 (left to right) is the first parameter in the calling sequence. The address of the input word is the second parameter; the standard FORTRAN-63 calling sequence is assumed.

NAME: SYLLABLE

ENTRY POINTS: SYLLABLE

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: SYLLKNT, TERMNAL6

PURPOSE: To double buffer input for SYLLKNT

INPUT: 700 word physical records on unit 6

OUTPUT: Seven word logical records in the first seven words of common block GII

ERROR STOPS:

A-Register

1 EOF in first record

2 Parity or buffer length error in first record

3 Parity or buffer length error in last record read into array MA

4 Parity or buffer length error in last record read into array LA

NOTES:

1. Any logical record whose first word consists of eight blank characters is skipped.
2. On the first EOF, TERMINL6 is called. The program exits to the monitor system on return from TERMINL6

NAME: SYLLKNT

ENTRY POINTS: SYLLKNT

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: CONVERT, OUTBLK, PHREV

PURPOSE: To count the number of syllables in a word and to abstract the vowel pattern.

INPUT: Standard dictionary format records (7 words), unconverted, in the first seven words of common block GII

OUTPUT:

A. Words 11-17 of common block HEE in the following format:

Character	
1	no. of syllables - BCD
2-4	blank
5-16	packed vowel pattern with stress mark - (converted characters, except 2= oʊ, 3= oɪ)
17-36	converted pronounciation, left justified
37-56	spelling, left justified
58-59	frequency (BCD)
60-63	blank
64	32_8

B. Words 8-27 of common block GII contain the converted pronounciation, one character per word, right justified with zero fill.

C. The first 10 words of common block HEE contain word counts for number of syllables/word. Word n ($1 \le n \le 10$) contains the number of words with n syllables (binary).

ERROR STOPS: None

NAME: TERMNAL6

ENTRY POINTS: TERMNAL6

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To terminate the reverse pronounciation and syllable count output.

INPUT:

A. Blocked output for the syllable counts in words 1-800 of common block POG

B. Syllable counts in words 1-10 of common block HEE

C. Blocked output for the reversed pronounciations in words 1-900 of common block SRT

OUTPUT:

A. UNIT 7; 800-word blocked record of syllable-count records. Unused words are filled with $44---4_8$. Logical record structure is output A of SYLLKNT

B. UNIT 51; Syllable count statistics in BCD for printing.

C. UNIT 8; 900-word blocked record of reversed prounciations. Unused words are filled with $44---4_8$. Logical record structure is output from PHREV

ERROR STOPS: A-Register

5 Parity error on 7 in output from OUTBLK

6 End-of-file or buffer length error

16 Parity error on unit 8 in output from SORTBLK

17 End-of-file or buffer length error on unit 8 in output from SORTBLK

NAME: SORTBLK

ENTRY POINTS: SORTBLK

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To block the output from PHREV for sorting

INPUT: Output from PHREV in the first nine words of common block JOG

OUTPUT: UNIT 8; 900-word blocked records. Logical records are the output from PHREV

ERROR STOPS: A-Register

22 Parity error on last output to Unit 8

23 End-of-file or buffer length error on last output to Unit 8

NAME: OUTBLK

ENTRY POINTS: OUTBLK

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: None

PURPOSE: To block the output from SYLLKNT for sorting.

INPUT: UNIT 7; 800-word blocked records logical records are output A from SYLLKNT

ERROR STOPS: A-Register

61 Parity error on last output to unit 7

62 End-of-file or buffer length error on last output to unit 7

NAME: PHREV

ENTRY POINTS: PHREV

SOURCE LANGUAGE: FORTRAN-63/1604

EXTERNAL SYMBOLS: SORTBLK

PURPOSE: To reverse the pronounciation of a word.

INPUT:

A. Converted pronounciations in words 8-27 of common block GII, one character/word, right justified with zero fill.

B. Output A from SYLLKNT

OUTPUT: Words 1-10 of common block HEE contain records in the following format:

Character	
1-20	Reversed pronounciation (converted)
21-24	blank
25-44	converted pronounciated, forward
45-64	spelling
65-66	frequency
67-71	blank
72	32_8

ERROR STOPS: None

NAME:	CONVERT
ENTRY POINTS:	CONVERT
SOURCE LANGUAGE:	FORTRAN-63/1604
EXTERNAL SYMBOLS:	None
PURPOSE:	To convert pronounciation symbols from two character to one character representations. After conversions are made, plus signs (+) are squeezed out.
INPUT:	Standard format unconverted dictionary records in the first 7 words of common block GII
OUTPUT:	Converted pronounciations symbols, one per word, right justified with zero fill in words 8-27 of block GII. The first 7 words of GII are not altered.
ERROR STOPS:	NONE
NOTES:	CHARACTER CONVERSIONS

INPUT	OUTPUT	INPUT	OUTPUT
A-	-	O)	8
A≠	-	U-	=
A8̸	8̸	U≠	■
A=	.	U.	Q
E-	4	U=	≠
E≠	4	SH	9
E.	5	TH	2
I-	6	CH	3
I≠	6	ZH	1
O-	7		
O≠	7		

STANDARD DICTIONARY FORMAT

Number of files: One, terminated by a single EOF mark

Recording density: 556 bpi

Recording mode: Even parity (BCD)

Physical record size: 700 words (8 char/words)

Logical record: (100/physical record)

Character

1-20	spelling	{left justified with blank fill
21-40	pronounciation	
41-42	frequency (1-20)	- BCD
43-50	blank	
51-55	code (1-20000)	BCD
56	32_8	

APPENDIX B

Word List

abandon
abandoned
abandonment
abase
abasement
abash
abate
abatement
abess
abbey
abbot
abbreviate
abbreviation
abdicate
abdication
abdomen
abdominal
abduct
abduction
abeam
abel
aberrant
aberration
abet
abeyance
abhor
abhorrence
abhorrent
abide
abiding
ability
abject
abjure
ablaze
able
ablution
ably
abnegation
abnormal
abnormality
aboard
abode
abolish
abolition
abolitionist
abominable
abomination
aboriginal
aborigines
abortion
abortive
abound
about
above
abrasion
abreast
abridge
abridgement
abroad
abrogate
abrupt
abscess
abscond
absence
absent
absent
absentee
absently
absolute
absolution
absolve
absorb
absorbed
absorbent
absorbing
absorption
absorptive
abstain
abstainer
abstemious
abstinence
abstract
abstracted
abstraction
abstruse
absurd
absurdity
abundance
abundant
abuse
abusive
abut
abutment
abysm
abyss
academic
academical
academy
accede
accelerate
acceleration
accelerator
accent
accent
accentuate
accept
acceptability
acceptable

acceptance
acceptation
access
accessibility
accessible
accession
accessory
accidence
accident
accidental
accidentally
acclaim
acclamation
acclimatize
acclivity
accomodate
accomodation
accompaniment
accompany
accomplice
accomplish
accomplished
accomplishment
accompt
accord
accordance
according
accordingly
accordion
accost
account
accountable
accountant
accounting
accouter
accredit
accrue
accumulate
accumulation
accuracy
accurate
accursed
accursed
accusation
accusative
accuse
accustom
accustomed
ace
acetate
acetic
acetylene
ache
achieve
achievement
acid
acidity
acknowledge
acknowledgment
acme
acne
aconite
acorn
acquaint
acquaintance
acquiesce
acquire
acquirement
acquisition
acquisitive
acquit
acquittal
acre
acreage
acrid
acrimonious
acrimony
acrobat
acrobatic
acrobatics
acromegaly
across
acrostic
act
acting
action
actionable
activate
activation
active
activity
actor
actress
actual
actually
actuate
acumen
acute
adage
adamant
adamantine
adapt
adaptability
adaptable
adaptation
adaptive
add
adder

addict
addicted
addiction
addition
additional
addle
address
adduce
adduct
adduction
adept
adequacy
adequate
adhere
adherence
adherent
adhesion
adhesive
adieu
adipose
adirondacks
adjacent
adjective
adjoin
adjourn
adjournment
adjudge
adjunct
adjuration
adjure
adjust
adjustable
adjustment
adjutant
administer
administration
administrative
administrator
admirable
admiral
admiralty
admiration
admire
admirer
admissible
admission
admit
admittance
admixture
admonish
admonition
ado
adobe
adolescence
adolescent
adopt
adoption
adorable
adoration
adore
adorn
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studio
studious
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zephyr
zeppelin
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zest
zigzag
zinc
zion
zip
zither
zodiac
zone
zoo
zoological
zoologist
zoology
zoom
zyme

FOOTNOTES

1. A rare form like *bayou* is an exception to this rule.

2. In either case, forms ending in ⟨-ue⟩ like *continue* and *virtue* must be handled separately.

3. The rules: 6. [c] [non-front vowel] → [s]

   7. [c] (ELSE) → [k]

   are equivalent to rules 3 and 4. The selection of 3 and 4 is based upon the general desire to base rules upon the presence rather than the absence of features whenever possible.

4. A few exceptions are *quack* and *whack*.

5. The retention or elision of [j] is described by the rules in Section 6.3 and plays no part in the morphophonemic alternation described here.

6. The ⟨t⟩ in this word corresponds to [s]. See Weir, 1964.

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